ACOUSTIC INSPECTION OF COATED STEEL BAR IN REINFORCED CONCRETE STRUCTURE

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INTRODUCTION

Bridges with reinforcement corrosion problems are now under careful inspection in Taiwan. Costly maintenance programs are underway and raising serious safety concern. There are various engineering solutions to salt-induced corrosion. Among them epoxy-coated reinforcing bars, commonly referred to as rebar, are frequently used in marine environment and other areas due to its durability, reasonable cost, and convenience. However, coated rebar has lower bond strength and is less ductile than uncoated rebar. Thus it could result in larger crack width during pull-out tests [1,2]. The bond strength between coated steel bars and covered concrete results from the adhesion at the steel-concrete boundary, the frictional force, and the interlocking force provided by the raised ribs at the steel bar surface. The interlocking force is much stronger than the other two, while the frictional force occurs only if the adhesion vanishes after delamination or disbonding starts.

The corrosion resisting performance of epoxy coated rebar has been studied by Rasheeduzzafar et al. [3]. Rebar corrosion status has been examined using the impact echo method [4]. Alternatively, the bonding situation was inspected using low-frequency ultrasound [5]. Due to the severe attenuation of sound waves in concrete, it was necessary to drive the piezoelectric transducer at a voltage higher than 500 volts. Current study demonstrated the feasibility of detecting the coating condition of rebar using B scans. Preliminary results showed clear connection existed between functioning coating and signal attenuation. Further investigation using high power sound waves such as tone burst signals generated by a gated amplifier was proposed.

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MEASUREMENT METHODS

To simulate a real-world structure member, concrete blocks with steel rebars are built and examined using a pair of piezoelectric transducers. Each transducer is 5 cm in diameter and driven by a pulser excited at a center frequency of 5.4 kHz. Effect of surface roughness is reduced by grinding both sides of the concrete block. The sound velocity is measured to be 4200 m/s. B scan is performed using standard through-transmission scheme. Signals are displayed on a Hewlett Packard 54600B digital oscilloscope. To attenuate some off-scale signal, a foam damper has to be placed between the silicone gel couplant and the specimen at the transmitter side.

Specimen

Non-air entrained concrete blocks are made of type I Portland cement. The mixture has a water-cement ratio of 0.49 with maximum aggregate size of 2.5 cm. In the preliminary study, a 2-cm-diameter steel bar of both smooth and ribbed surfaces is used in concrete blocks A and B, respectively. The rebar is partially wrapped in its mid section by a 1.5 mm-thick layer of foamed material, as shown in Figure 1. To avoid geometric symmetry, the rebar is centered at 6 cm from one side of the concrete block, about one-third of its width. The specimen is cured in water at 38 ℃ for seven days.

MEASUREMENT RESULTS

The peak to peak voltage is recorded when measurements are taken along the rebar inside block A, as shown in Figure 2. Significant decay is observed in the middle section of the specimen, corresponding to the foam-wrapped rebar. The voltage drop at 12 cm could be due to internal defect of the concrete or operational error. The measurement results for block B are shown in Figure 3. Signal intensity for Block A is much higher than that for block B due to the fact that ribbed rebar in B deflects sound waves considerably. It should also be noted that A has been examined immediately after it is taken out of water, while B has been left to dry for a day before it is inspected. Similar voltage drop due to the foam-wrapped section of rebar in B is also observed as shown in Figure 3.

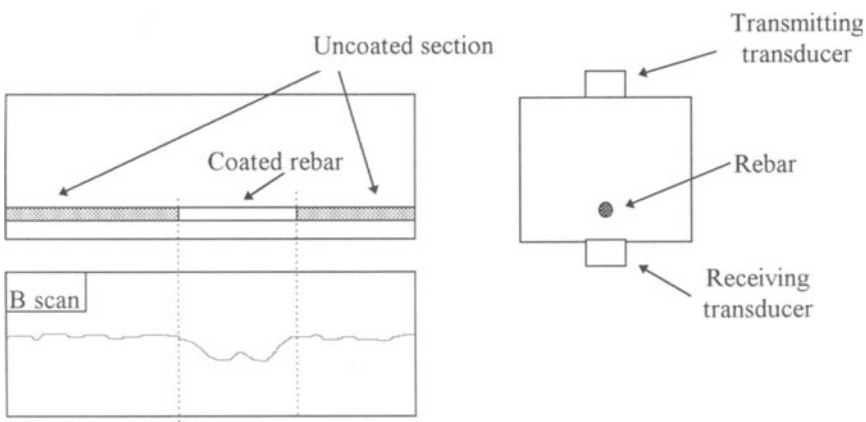

Figure 1. Rebar in a concrete specimen for experiment setup.

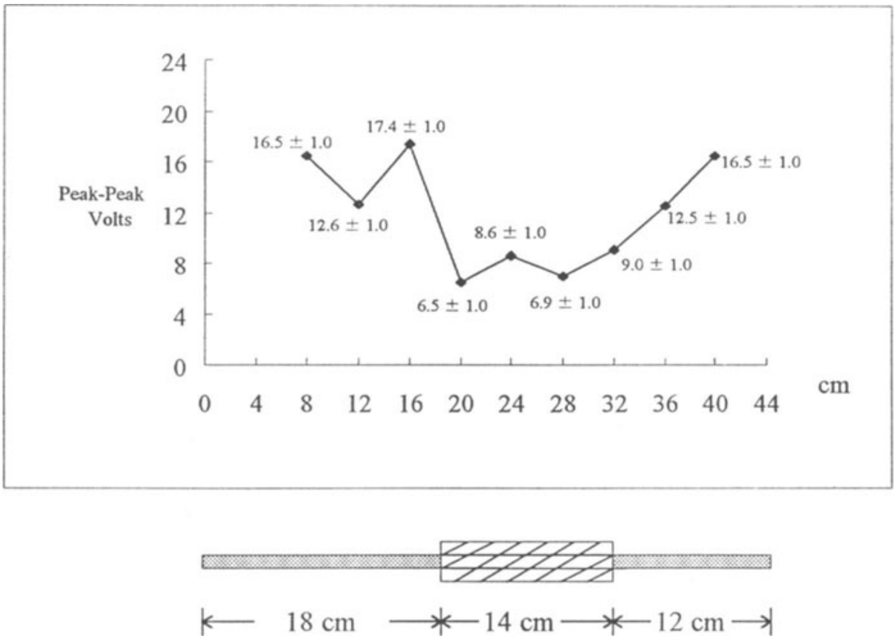

Figure 2. Recorded B-scan along the rebar direction of test block A. Voltage is measured directly from digital oscilloscope.

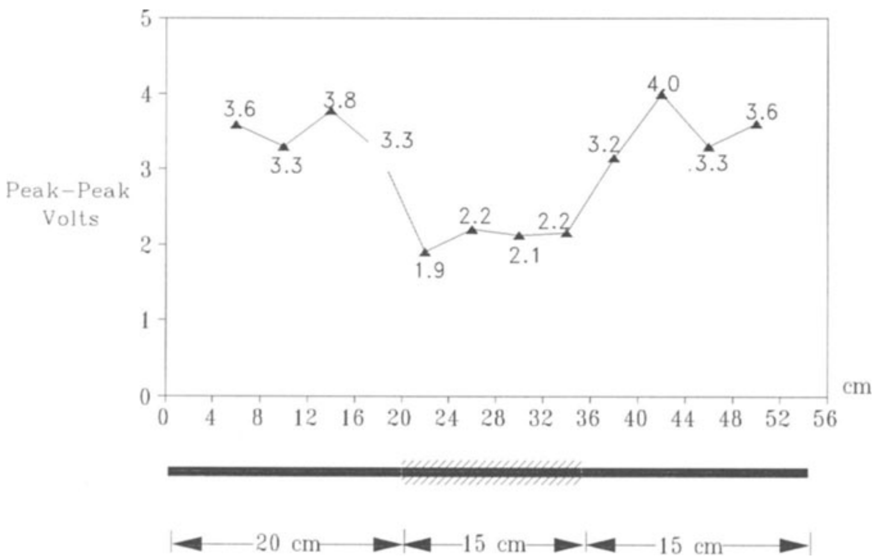

Figure 3. Recorded B-scan along the rebar direction of test block B.

DISCUSSION

The highly attenuative nature of concrete usually creates problem for regular ultrasonic testing. However, good results have been shown using high power, low frequency sound wave. Steel reinforced concrete is essentially a fairly nonuniform and partially inelastic material. Similar to the problem associated with examining fiber-reinforced composites, nondestructive evaluation of rebar corrosion calls for more than one testing procedure [1] and encounters even greater challenges. In this study, surface treatment of concrete specimens contributes to an excellent signal-to-noise ratio and needs to be simplified for easier on-site inspections. Moreover, through-transmission inspection is simple but impractical since most structure members are only accessible from one side. Further research has to be conducted before the pulse echo method may be adopted.

In order to keep the variance in contact pressure due to different operators from changing effective coupling, a new type of transducer holder is designed. The holder is capable of adjusting the holding pressure and keeping the pressure constant. It is anticipated that the fine-finish grinding procedure, for concrete blocks used in the laboratory, should be avoided in on-site testing. Malt sugar is going to be one of the candidates to be used as the couplant after minimum surface grinding.

CONCLUSION

The interface of rebar and covered concrete has been examined using high power sound waves. Foam-wrapped rebar is used to simulate epoxy coated rebar. Transmission type B scan is performed over two test concrete blocks. Measurement results show significant attenuation of sound waves due to the rebar coating. There is not enough evidence of how the thickness of coating affects the signal attenuation. Signal attenuates more severely after disbonding and delamination occur. As the bond splitting progresses, bond strength starts to decay due to the decreasing adhesion force. Only limited amount of friction is present and the smooth-surfaced rebar provide much less interlocking force than ribbed rebar. Pull-out tests indicate lower bond strength for coated rebar than bare rebar. The fracture mechanism has been studied extensively for the bond splitting failures of ribbed rebar [6]. However, the interlocking force, which plays a key role on the bond strength evaluation, remains to be investigated.

Almost all nondestructive techniques are complementary and require both probing and post-analysis. If one were to select a straightforward, easily-interpreted, and risk-free inspection scheme, an imaging system should be the most logical choice. Radiography is usually considered potentially risky to the inspecting personnel, despite the fact it is reasonably effective. Acoustic emission requires a large amount of sensor network, expensive data acquisition and complex analysis. Impact echo and similar impact methods are quite practical in terms of the equipment portability and procedural simplicity. However, these types of work are still limited to local crack detection of concrete structures with exception of the Rayleigh wave dispersion method which can be used to evaluate the stiffness properties of layered concrete structures [7]. Current research shows the feasibility of constructing a field inspection system which not only can provide a quick scan on site, but may also be extended to produce surface and interior images for further analysis. Since ultrasonic testing has been successfully developed for both industrial and medical applications, similar techniques using piezoelectric transduction would be very suitable for the purpose of field inspection for reinforced concrete structures.

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